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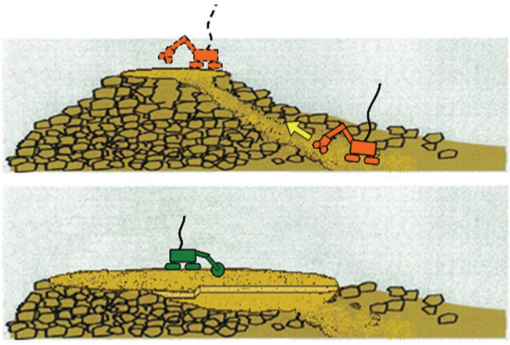
Development of Mining Element Engineering Test Machine for Operating in Seafloor Hydrothermal Deposits



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Seafloor hydrothermal deposits (also referred as seafloor massive sulfide deposits, or SMS deposits) are plentiful in the waters off of Japan. SMS deposits are promising mineral resources for resource-poor Japan. A joint venture of Mitsubishi Heavy Industry (MHI) (the representative of the JV), Kayaba System Machinery Co., Ltd., and Sumitomo Metal Mining Co., received an order of a Mining element engineering test machine to collect technical data necessary to construct SMS mining systems. The test machine was constructed in March 2012 and delivered to Japan Oil, Gas and Metals National Corporation (JOGMEC). We conducted an offshore examination with this test machine to excavate an SMS deposit at the bottom of the sea in Okinawa's waters in Nov. 2012 and successfully collected the samples by using a slurry pump.

1. Introduction

Japan has many SMS deposits in its exclusive economic zone (EEZ). It is estimated that several deposits are located at economically feasible, relatively shallow water depths of approx. 1,000m–1,600m. SMS deposits are rich in copper, zinc, gold, and silver and also expected as rare-metal resources. It is an urgent task for resource-poor Japan to develop the SMS deposits. In order to commercialize these deposits, it is required to construct a pilot plant for an ocean examination for actual proof.

Before constructing the pilot plant, we conducted a Mining element engineering test machine in order to collect technical data for mining unit.

Firstly we conducted element tests for an excavating device, a dredging device, and a crawler device, and constructed a Mining element engineering test machine based on the test results. This test machine was installed on the marine resource research vessel, Hakurei, to run on an actual deposit in an offshore examination.

This report outlines the element tests (for the excavating device, dredging device, and crawler device), construction of the Mining element engineering test machine, and the offshore examination.

2. Element tests

2.1 Mining operations and mining heads

(1) Mining system

In contrast with submarine fluid resources including oil and gas, SMS deposits are commercially available only by excavating, collecting, refining heavy density ores from deep-sea areas, and then raising them to the sea surface and transporting them to the smelters. SMS core sampling operations have been carried out on a trial basis, but large-scale commercial mining with a mining system has not yet to be attempted because of the extreme conditions of the deep sea.

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Figure 1 is a schematic view of the proposed mining system. This mining system consists of a mining support vessel, a mining machine, a submerged pump unit, a riser pipe, etc. The mining machine is remotely controlled with a controller on the support vessel through an umbilical cable. The mining machine collects and dredges ores. A submerged pump connected with the machine through a flexible pipe lifts the ores up to the support vessel through a riser pipe. The recovered ores are stored in the hold of the mining support vessel and transported to the smelters by another ships.

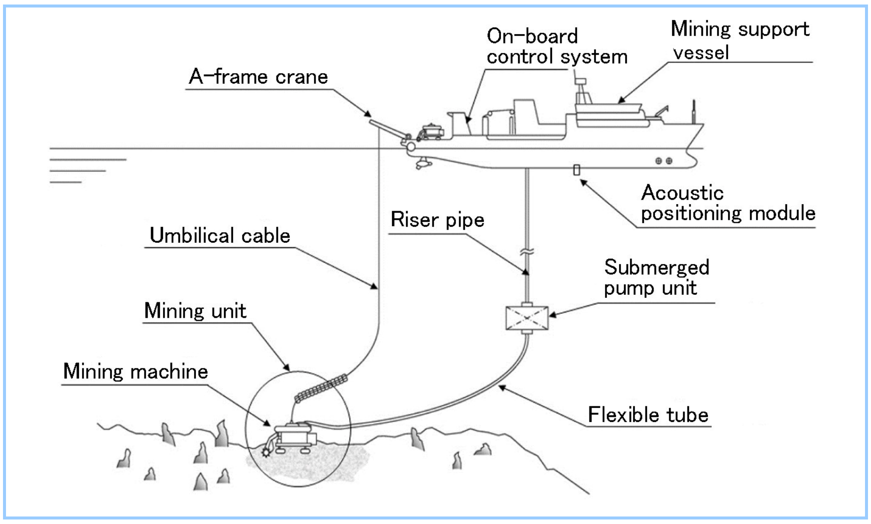


Figure 1 Proposed mining system
The mining system consists of a mining support vessel, a riser pipe, and a mining unit.

(2) Mining operations and excavation cutting heads

SMS deposits are covered with breccia and sometimes with chimneys. Before main excavation operations with a highly-efficient bench cut method, a pre-excavation is required to remove the breccia and chimneys. This approach needs two types of cutter heads; for pre-excavation and for main excavation operations. Consequently, it also needs two types of mining machines; an auxiliary mining machine and a primary mining machine. Unlike onshore mining operations where excavation and recovery are conducted separately, offshore mining operations require a different approach for higher productivity and recovery rates. Specifically, excavation and dredging operations should be conducted simultaneously to reduce the mining duration and costs associated with the equipment in the support vessel. Both mining machines should use a cutter head that simultaneously serves excavation and dredging operations.

For main excavation operations, we selected drum cutters commonly used in mining or construction equipment, such as load cutters (as shown in **Figure 2**a). For pre-excavation operations, we developed a multi-axis (4-axis) cutter to flexibly cut large breccia and chimneys, and effectively dredge them. A schematic view of the 4-axis cutter is shown in Figure 2b.

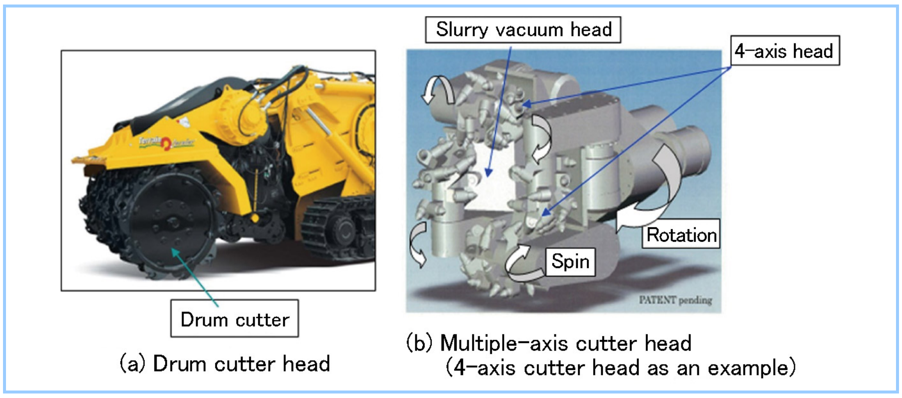


Figure 2 Excavation cutters
In the excavation operation we separately uses two-types cutter head. The main excavation operation uses a drum cutter head. The pre-excavation operation uses a multi-axis cutter head. Simultaneous excavating and dredging is possible with a single device, resulting in a higher recovery rate. Peripheral excavation heads of the 4-axis cutter collect ores at the head's center. The vacuum head sucks the ores by a slurry transport method.

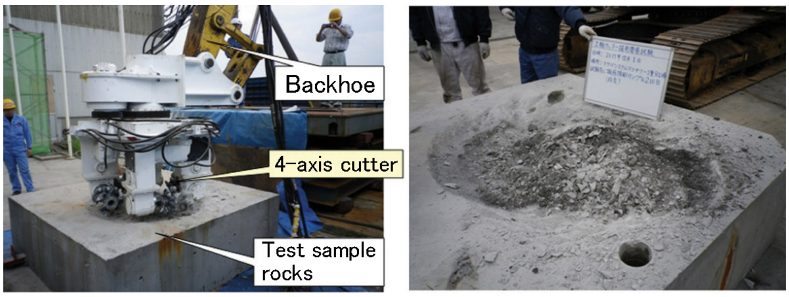
A 4-axis cutter excavates the ground in a toric shape. The paired cutters of a 4-axix cutter spin and rotate to collect the pulverized ore soil to the center of the cutter head. The pulverized soil is dredged with a vacuum head at the center of the cutter head. The vacuumed soil is transported to the test machine body through a slurry transportation method. A 2-axis head is also available.

2.2 Element tests for excavating device

Based on the concept described in the Chapter 2.1, we selected a drum cutter and a 4-axis cutter as the excavating heads to be used in the Mining element engineering test machine. Before building the test machine, we conducted elemental tests for the excavating device with a drum cutter and for the device with a 4-axis cutter.

In the element test for the drum cutter, we selected one for onshore earth-moving machines. We assessed the basic performance, including excavation torque, reactive force, and soil volume for four test samples: 20 MPa and 50 MPa concrete blocks, SMS deposit ore rocks, and serpentine rocks. The test showed that the excavating device fitted with the drum cutter should generally demonstrate the specifications and required performance as planned. The grain sizes of the pulverized samples were stable and controlled by changing excavation conditions.

In the element test for the 4-axis cutter, we fabricated an excavating device fitted with a 4-axis cutter, assuming that it would be installed in the Mining element engineering test machine. **Figure 3** shows the situations of the element test for the 4-axis cutter.



(a) Test conditions (b) After excavation

Figure 3 Element test for the excavating device fitted with a 4-axis cutter

Paired excavation cutters rotate and spin, cutting the test sample in a toric-shape. During actual mining operations, the excavated soil is collected to the center of the head and sucked by the vacuum head placed at the center, transporting the slurry from the seafloor to the sea surface.

The test showed that the 4-axis cutter had an insufficient excavation capability of only 0.1 to 0.3 m^3/h. The reason was because the limited hydraulic-pressure was split between the four drums, resulting in poor performance of each drum. Then, we fabricated a 2-axis cutter to reduce the number of drums from four to two. We also increased the drum diameters and the peripheral velocities.

Consequently, we modified the excavating device to test the 2-axis cutter. The cutter showed good excavation capacity of 1.2 m^3/h for the SMS sample. The device also excavated the serpentine rocks (single axis compressive strength: 70 to 170 MPa) which overwhelmed the 4-axis cutter. This effective modification significantly improved the excavating performance, and paved the way for installing the excavating device into the test machine. The soil collection performance rivals the 4-axis cutter. The grain size distribution of the pulverized soil was also stable.

2.3 Element test for dredging device

The main excavation operations require simultaneous excavation and dredging. Hence we fabricated a head by combining a dredging head with the excavation heads of both a drum cutter and a 4-axis cutter. We conducted an element test in a test tank, and used two samples: crushed rocks and mud. The fabricated heads did not excavate but imitated only recovery of the test samples to assess only their dredging performance.

Figure 4 shows the assumed flow of the soil in the dredging head. The test confirmed that each dredging head cleanly collect and transport all the crushed rocks in the slurry up to the rated capacity of the slurry pump.

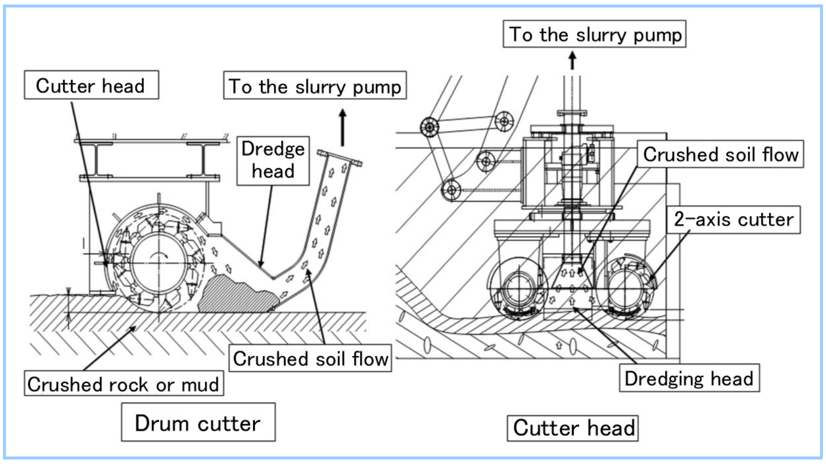


Figure 4 Element test for the dredging system (slurry flow by the dredging head (Imaging))
The crushed soil are gathered to the front of the dredge head by the spin and rotation of the cutter and vacuumed and slurry-transported by the slurry pump.

2.4 Element test for crawler device

SMS deposits are commonly covered with rugged terrain, and it is difficult for conventional crawler devices to run on. Hence, we developed a suspended-style vehicle that is independently supported by four crawlers. The lengths and angles of the crawlers' legs are adjustable to improve the running performance on rugged terrain.

In the element test for the crawler device, we arranged a test-bed made of crushed rocks to assess the running performance on rugged terrain as well as the basic performance. **Figure 5** shows the element test for the crawler device.

Figure 5 Element test for the crawler device
This figure shows 4-crawler test-bed running on a wasteland made of crushed rock.

3. Mining element engineering test machine

Mining element engineering test machine has a front-boom that swings to the right/left and moves up/down. The boom has two types of cutters on its end: a drum cutter and 2-axis cutter. The former cuts the ground evenly. The latter cuts ground right in front of the machine and roughly cut uneven ground. A dredging head is attached to each of the two heads. Consequently, a feature of the test machine is that it simultaneously performs both excavation and dredging. The test machine with the four crawlers runs on the seafloor, climb hills with up to an inclined angle of 35 degrees, and over steps up to 35 cm in height.

Figure 6 shows a outline of Mining element engineering test machine.

Commercial mining machines will be a 1,000 kW-class underwater system weighing 120 metric tons. Although this test machine is only a 184 kW-class system weighing 20 metric tons, it is still twice the size of general work class underwater ROVs (Remotely Operated Vehicles) and provides sufficient heavy-duty performance.

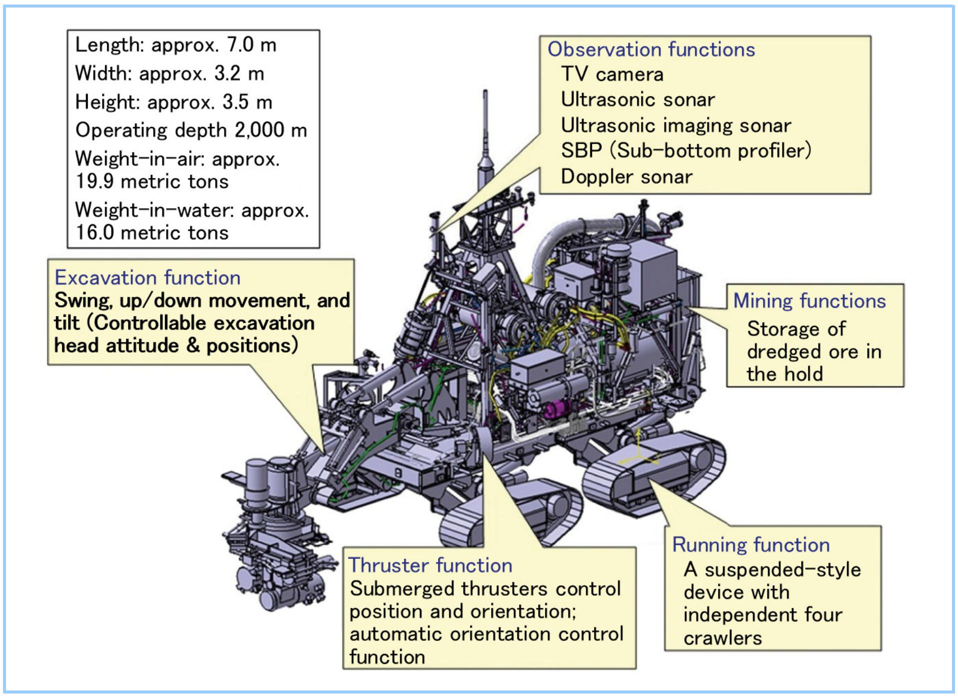


Figure 6 Mining element engineering test machine
A schematic view of Mining element engineering test machine fitted with a 2-axis cutter head

4. Offshore examination

Mining element engineering test machine was installed on a marine resource research vessel, Hakurei, and an offshore examination was carried out in the waters off of Okinawa in Nov. 2012. The test machine landed on a modest slope terrain with chimneys (from 2 to 5 m in height), avoiding rough areas. The possible landing sites were very narrow because there were large (2 to 5 m) and small (approx. 1 m) chimneys and chimney fragments in the test field.

Figure 7 shows the 2-axis cutter excavating these chimneys. This test machine collected approx. 25 kg SMS samples and stored them in the hold. The grain size distribution of the samples was consistent with no grains over 50 mm, demonstrating stable excavation performance. **Figure 8** shows the collected samples and grain size distribution.

Achievements on the offshore experiment and future tasks are described below.

(1) SMS sample recovery

We operated Mining element engineering test machine at an actual SMS deposit mound under deep-sea conditions to assess its performance and behavior. This test machine successfully cut the seafloor and chimneys and collected the SMS samples.

(2) Collection of operation data

We collected valuable operation data using this test machine on actual ore deposits on the seafloor. We successfully gained information which will be useful for constructing a future pilot plant.

(3) Importance of assessing seafloor conditions

The target terrain of this offshore examination was covered with sedimentary layers. The dust particles were disturbed and clouded the seawater when the test machine landed, obscuring the seafloor. Breccia and small chimneys also created risky conditions. For safety reasons, several TV cameras and SONAR devices are essential to understand the conditions of the target terrain and its surrounding area during the operations.

(4) Heavy-duty operation performance

Commercial mining machines, which are categorized as earth-moving machinery, should have sufficient heavy-duty operation performance. They should also have sufficiently protection and durability to withstand contact with breccia and mining targets.

(5) Excavation heads and mining target monitoring

Effective mining operations require the careful monitoring of the excavation cutting heads and their surroundings. In this respect, multiple sensors to monitor head conditions are desired.

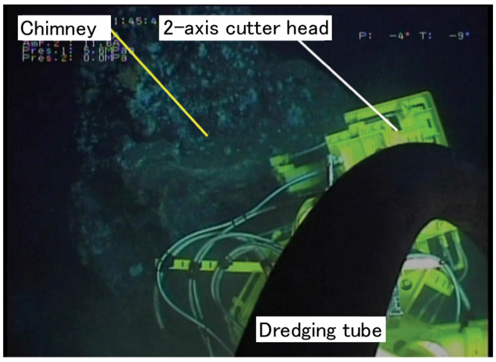


Figure 7 Excavating chimney
The appearance of the 2-axis cutter head cutting chimney.

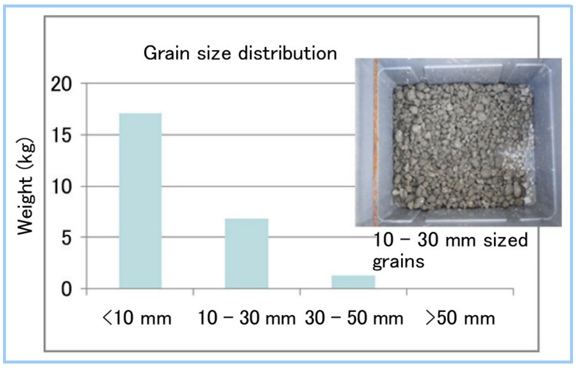


Figure 8 Grain size distribution of the collected SMS samples
This chart shows stable excavation/dredging performance and no grains over 50 mm.

5. Conclusion

We developed Mining element engineering test machine based on the element tests for the excavating device, dredging device, and crawler device. In the offshore examination in November 2012, we successfully operated this test machine on the actual SMS mound deep underwater, and collected the SMS samples. This offshore examination provides us with valuable operation data and useful knowledge for constructing the future pilot plant.

We would like to express our appreciation to JOGMEC for their excellent support in the construction of Mining element engineering test machine.

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